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(71) Applicant: SANDVIK AB (publ) [SE/SE]; S-811 81 Sandviken (SE).

(72) Inventors: SJÖSTRAND, Mats; Imatragatan 328, S-164 78 Kista (SE). SELINDER, Torbjörn; Katrinebergsbacken 18, S-117 61 Stockholm (SE). NORDIN, Maria; Salavägen 15C, S-753 30 Uppsala (SE). LARSSON, Mats; Bellmansgatan 144, S-754 26 Uppsala (SE). HOGMARK, Sture; Hangargatan 4, S-753 37 Uppsala (SE).

(74) Agent: TÅQUIST, Lennart; Sandvik AB, Patent Dept., S-811 81 Sandviken (SE).

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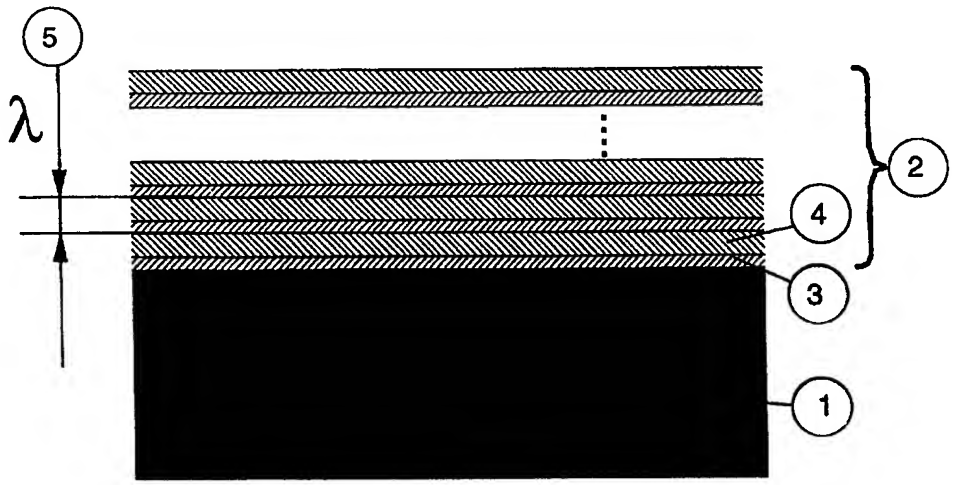
(54) Title: MULTILAYERED COATED CUTTING TOOL



(57) Abstract

The present invention relates to a cutting tool comprising a body (1) of sintered cemented carbide or cermet, ceramic or high speed steel on which at least on the functioning parts of the surface of the body, a thin, adherent, hard and wear resistant coating (2) is applied. The coating comprises a laminar, multilayered structure of refractory compounds in polycrystalline, repetitive form, (MX/NX) λ/(MX/NX)λ/MX/NX)λ/(MX/NX)λ/... where the alternating layers MX (3) and NX (4) are composed of metalnitrides or carbides with the metal element selected from Ti, Nb, Hf, V, Ta, Mo, Zr, Cr and W. The repeat period λ (5) is essentially constant throughout the entire multilayered structure, and larger than 3 nm but smaller than 100 nm, preferably smaller than 25 nm. The total thickness of said multilayered coating is larger than 0.5 μm but smaller than 20 μm.

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MULTILAYERED COATED CUTTING TOOL

The present invention relates to a cutting tool for metal machining, having a substrate of cemented carbide, cermet, ceramics or high speed steel and, on the surface of said substrate, a hard and wear resistant refractory coating is deposited by Physical (PVD) or Chemical (CVD) Vapour Deposition. The coating is adherently bonded to the substrate and is composed of a laminar, multilayered structure of metal nitrides or carbides with a repeat period in the *nanometer range (nm)* and the metal elements of the nitride or carbide are selected from Ti, Nb, Hf, V, Ta, Mo, Zr, Cr or W.

The present invention relates particularly to the art of PVD coated carbides or similar hard materials such as cermets, ceramics and high speed steels. The method of depositing a thin refractory coating (1-20 μm) of materials like alumina (Al_2O_3), titanium carbide (TiC) and/or titanium nitride (TiN) onto e.g. a cemented carbide cutting tool is a well established technology and the tool life of the coated cutting tool, when used in metal machining, is considerably prolonged. The prolonged service life of the tool may under certain conditions extend up to several 100 percent. Said refractory coatings in the Prior Art comprise either a single layer or a combination of multilayers. Modern commercial cutting tools are characterised by a plurality of layer combinations with double or multilayer structures. The total coating thickness varies between 1 and 20 micrometers (μm) and in the prior art, the multilayered structure is characterised in *the micrometer range (μm)*, i.e. the thickness of the individual sublayers varies between a few microns and a few tenths of a micron.

The established technologies for depositing such coatings are CVD (Chemical Vapour Deposition) and PVD

(see e.g. *US 4,619,866* and *US 4,346,123*). PVD coated commercial cutting tools of cemented carbides or high speed steels usually have a single coating of TiN, TiCN or TiAlN, but combinations thereof also exist.

There exist several PVD techniques capable of producing refractory thin films on cutting tools. The most established methods are ion plating, magnetron sputtering, arc discharge evaporation and IBAD (Ion Beam Assisted Deposition). Each method has its own merits and the intrinsic properties of the produced coating such as microstructure/grain size, hardness, state of stress, cohesion and adhesion to the underlying substrate may vary depending on the particular PVD method chosen. An improvement in the wear resistance or the edge integrity of a PVD coated cutting tool being used in a specific machining operation can thus be accomplished by optimizing one or several of the above mentioned properties. Furthermore, new developments of the existing PVD techniques by, for instance, introducing unbalanced magnetrons in reactive sputtering (*S. Kadlec, J. Musil and W.-D. Munz in J. Vac. Sci. Techn. A8(3), (1990), 1318.)* or applying a steered and/or filtered arc in cathodic arc deposition *(H. Curtins in Surface and Coatings Technology, 76/77, (1995), 632 and K. Akari et al in Surface and Coatings Technology, 43/44, (1990), 312.)* have resulted in a better control of the coating processes and a further improvement of the intrinsic properties of the coating material.

Conventional cutting tool materials like cemented carbides consist of at least one hard metallic compound and a binder, usually cobalt (Co), where the grain size of the hard compound, e.g. tungsten carbide (WC), ranges in the 1-5 µm region. Recent developments have predicted improved tool properties in wear resistance, impact strength, hot hardness by applying tool materials based

on ultrafine microstructures by using nanostructured WC-Co powders as raw materials (*L.E. McCandlish, B.H. Kear and B.K. Kim, in NanoSTRUCTURED Materials VOL. 1 pp. 119-124, 1992*). Similar predictions have been made for ceramic tool materials by for instance applying silicon-nitride/carbide-based (Si_3N_4/SiC) nanocomposite ceramics and, for Al_2O_3-based ceramics, equivalent nanocomposites based on alumina.

With nanocomposite nitride or carbide hard coating materials, it is understood a multilayered coating where the thickness of each individual nitride (or carbide) layer is in the nanometer range, 3-100 nm or preferably 3-20 nm. Since a certain periodicity or repeat period of e.g. a metal nitride film sequence is invoked, these nanoscaled, multilayer coatings have been given the generic name of "superlattice" films. A repeat period is the thickness of two adjacent metal nitride layers i.e. with different metal element in the sublayers. Several of the metal nitride superlattice coatings with the metal element selected from Ti, Nb, V and Ta, grown on both single- and polycrystalline substrates have shown an enhanced hardness for a particular repeat period usually in the range 3-10 nm.

According to the present invention, there is provided a cutting tool comprising a body of a hard alloy of cemented carbide, cermet, ceramics or high speed steel, onto which a wear resistant, multilayered coating has been deposited. More specifically, the coated tool comprises a substrate of sintered cemented carbide or a cermet, preferably of at least one metal carbide in a metal binder phase, or a ceramic. The substrate may also comprise a high speed steel alloy. Said substrate may also be *precoated* with a thin single- or multilayer of TiN, TiC, TiCN or TiAlN with a thickness in the *micrometer range* according to prior art. The coated cutting

tool according to the present invention exhibits improved wear resistance and toughness properties compared to prior art tools when used for machining steel or cast iron and, in particular, stainless steel. Said coating, which is adherently bonded to the substrate, comprises a laminar, multilayered structure of metal nitrides or carbides, preferably of binary polycrystalline nitrides, having a thickness of 0.5 to 20 μm, preferably 1 to 10 μm, most preferably 2 to 6 μm. In the binary, multilayered coating structure (see Fig. 1) $(MX/NX)_{\lambda}/(MX/NX)_{\lambda}/(MX/NX)_{\lambda}/(MX/NX)_{\lambda}/$........., the alternating layers MX and NX comprise metalnitrides or metalcarbides with the metal element M and N selected from titanium (Ti), niobium (Nb), hafnium (Hf), vanadium (V), tantalum (Ta), molybdenum (Mo), zirconium (Zr), chromium (Cr) or tungsten (W), the repeat period λ in $(MX/NX)_{\lambda}$ is essentially constant throughout the entire multilayer structure (that is, it varies by no more than 20%) and is larger than 3 nm but smaller than 100 nm, preferably smaller than 50 nm, most preferably smaller than 25 nm. The repeat period is the thickness of the layers MX + NX, i.e. two adjacent layers with different metal elements. Preferred examples of the above "superlattice" coatings are TiN/NbN/TiN/NbN/...., TiN/TaN/TiN/TaN/.... and TiN/VN/TiN/VN/.....

Referring to Fig.1 there is shown a substrate ***1*** coated with a laminar, multilayered nitride or carbide coating ***2*** with the individual binary metalnitride (or carbide) layers being MX ***3*** and NX ***4*** and where the repeat period λ ***5***, the thickness of the binary layers MX + NX, is essentially constant throughout the entire multilayer coating.

The laminar coatings above exhibit a columnar growth mode with no or very little porosity at the grain boundaries. The coatings also possess a substantial

waviness in the sublayers which originates from the substrate surface roughness. High magnification transmission electron microscopy (TEM) indicates a very ordered superlattice structure with sharp interfaces and, furthermore, X-ray diffraction of the superlattice structure of the coating also supports the observation that the local structure is ordered. Nevertheless, regardless of the superlattice reflection in the X-ray diffractograms, these coatings on cemented carbides, cermets, ceramics or high speed steel substrates are by no means single crystals and should consequently be regarded as multilayers or "lamellae coatings" rather than superlattices due to the relatively high degree of disorder in the local structure.

For a cutting tool used in metal machining, several advantages are provided by the present invention with nanostructured lamellae coatings deposited on substrates of hard, refractory materials such as cemented carbides, cermets and ceramics. E.g. in a binary nitride lamellae coating $(MX/NX)\lambda/$ $(MX/NX)\lambda/$ .... on cemented carbides, the hardness of the coating is usually enhanced over the individual single layers of MX and/or NX with a layer thickness on a µm scale, simultaneously as the intrinsic stress numerically is smaller. The first observation, enhanced hardness in the coating, results in an increased abrasive wear resistance of the cutting edge while the second observation of numerically less intrinsic stress in the coating, provides an increased capability of absorbing stresses exerted on the cutting edge during a machining operation.

The laminar, nanostructured coatings can be deposited on a carbide, cermet, ceramic or high speed steel substrate either by CVD or PVD techniques, preferentially by PVD techniques, by successively forming individual sublayers by vapour deposition in a vacuum cham-

ber. Electron beam evaporation, magnetron sputtering or cathodic arc deposition or combinations thereof, are the preferred PVD methods for depositing the nanostructured coatings.

Example 1

Multilayered TiN/NbN coatings were deposited on cemented carbide (WC/9w%Co) cutting inserts of ISO insert style SEKN 1204 designed for a face milling cutter. The inserts were mounted on a rotating sample holder in a PVD vacuum chamber and the TiN/NbN lamellae coating was deposited by the simultaneous deposition of TiN and NbN by applying a substrate table rotation of 10 rpm. Titanium was e-gun evaporated from a crucible while Nb was sputtered off a magnetron target. Nitrogen was added to the vacuum chamber as the reactive gas. The resulting total coating thickness was approximately 4 µm and varied less than 20% between the flank and rake face of the coating. Accordingly, the "superlattice" repeat period on the different tool surfaces exhibited only small variations. The individual thicknesses of the sublayers, the lamellae thicknesses, were approximately 7 nm for the TiN layers and approximately 5 nm for the NbN layers i.e. the repeat period λ was approximately 12 nm. The microhardness of the TiN/NbN lamellae coating was 3200 HV and the residual intrinsic stress was -0.5 GPa.

The multilayered, nanostructured TiN/NbN coated cutting inserts were tested in a face milling machining operation in austenitic stainless steel (AISI/SAE 303/304) against PVD TiCN (4 µm thick) single-coated cemented carbide inserts also of insert style SEKN 1204 and WC/Co composition WC/9w%Co. Hence, any substrate composition or insert style effects on the machining results were ruled out. The cutting test was performed under dry cutting conditions in a one-tooth face milling

operation with a Φ100 mm milling cutter centered on the work piece. The work piece material was in the form of 600 mm long bars of width 50 mm and the machining performance of the tools was evaluated by measuring the average flank wear of the cutting edge after each passage of 600 mm.

Cutting data:

Cutting speed	166 m/min
Feed rate	0.12 mm/tooth
Depth of cut	4 mm

The results below are expressed as the average flank wear (mm) of the cutting tool after a milled length of 3000 mm:

	average flank wear (mm)
Multilayered, nanostructured TiN/NbN coated cutting inserts:	0.15
PVD TiCN single-coated cutting inserts:	0.50

Example 2

Multilayered TiN/TaN coatings were deposited on cemented carbide (WC/9w%Co) cutting inserts of ISO insert style SEKN 1204 using the coating technique described in Example 1. The thicknesses of the individual sublayers were approximately 7 nm for the TiN layers and approximately 4 nm for the TaN layers, yielding a repeat period λ of 11 nm.

The multilayered, nanostructured TiN/TaN coated cutting inserts were tested in a face milling machining operation in austenitic stainless steel (AISI/SAE 303/304) against single-layer PVD TiCN (4 µm thick) and single-layer PVD TaN (4 µm thick) coated cemented carbide inserts also of insert style SEKN 1204 and WC/Co composition WC/9w%Co. Hence, any substrate composition

or insert style effects on the machining results were ruled out. The cutting test was performed under dry cutting conditions in a one-tooth face milling operation with a Φ100 mm milling cutter centered on the work piece. The work piece material was in the form of 600 mm long bars of width 50 mm and the service lives of the tools were determined by measuring the milled length until tool failure which was when edge chipping occurred or when the flank wear exceeded 0.50 mm.

Cutting data:

Cutting speed	172 m/min
Feed rate	0.12 mm/tooth
Depth of cut	4 mm

The results below are expressed as the milled length until cutting tool failure:

	milled length (mm)
Multilayered, nanostructured TiN/TaN coated cutting inserts:	3130
PVD TiCN single-coated cutting inserts:	1900
PVD TaN single-coated cutting inserts:	610

Example 3

Multilayered TiN/NbN coatings were deposited on cemented carbide inserts of three different compositions. The inserts were designed for an end milling cutter and the three WC/Co carbide compositions were: WC/6w%Co, WC/9%Co and WC/12%Co. The same coating technique as in Example 1 was used and the individual sublayers thicknesses and the repeat period were also the same as in Example 1.

The TiN/NbN multilayer coated cutting inserts were tested in an end milling machining operation in austenitic stainless steel (AISA/SAE 303/304) against single-

layer PVD TiN (4 µm thick) coated cemented carbide inserts with the same compositions as given above. The cutting test was performed under dry cutting conditions with a Φ16 mm insert end mill in a side milling operation. The work piece material was in the form of 500 mm long bars. The service lives of the tools were determined by measuring the milled length until tool failure which was when edge chipping occurred or when the average flank wear exceeded 0.50 mm.

Cutting data:

Cutting speed	150 m/min
Feed rate	0.14 mm/tooth
Depth of cut/cutting width	4.0/8.0 mm

The results below are expressed as the milled length until cutting tool failure:

	milled length (mm)
WC/6w%Co	
Multilayered nanostructured TiN/NbN coated cutting inserts:	800
PVD TiN single-coated cutting inserts:	600
WC/9w%Co	
Multilayered nanostructured TiN/NbN coated cutting inserts:	3050
PVD TiN single-coated cutting inserts:	2100
WC/12w%	
Multilayered nanostructured TiN/NbN coated cutting inserts:	7250
PVD TiN single-coated cutting inserts:	4900

Claims

1. Cutting tool comprising a body of sintered cemented carbide or cermet, ceramic or high speed steel and on which at least on the functioning parts of the surface of the body, a thin, adherent, hard and wear resistant coating is applied, said coating ***characterised*** in comprising a laminar, multilayered structure of refractory compounds in polycrystalline, repetitive form, $(MX/NX)\lambda/(MX/NX)\lambda/\ (MX/NX)\lambda/(MX/NX)\lambda/\ldots\ldots$ where the alternating layers MX and NX are composed of metalnitrides or carbides with the metal element selected from Ti, Nb, Hf, V, Ta, Mo, Zr, Cr and W, and where in said coating the repeat period λ is essentially constant throughout the entire multilayered structure, and where the said repeat period is larger than 3 nm but smaller than 100 nm, preferably smaller than 25 nm, and that the total thickness of said multilayered coating is larger than 0.5 µm but smaller than 20 µm.

2. Cutting tool according to claim 1 ***characterised*** in that the alternating layers MX and NX are composed of metalnitrides.

3. Cutting tool according to claim 1 ***characterised*** in that the alternating layers MX and NX are composed of metalcarbides.

4. Cutting tool according to any of the preceding claims ***characterised*** in that the metal elements in the alternating layers MX and NX are Ti resp. Nb.

5. Cutting tool according to claim 1 - 3 ***characterised*** in that the metal elements in the alternating layers MX and NX are Ti resp. Ta.

6. Cutting tool according to any of the preceding claims **characterised** in that the repeat period λ ranges from 3 to 50 nm, preferably from 3 to 25 nm.

7. Cutting tool according to any of the preceding claims **characterised** in that said coating has a total thickness of 1 to 10 µm, preferably from 2 to 6 µm.

8. Cutting tool according to any of the preceding claims **characterised** in that said body is a cemented carbide or a cermet.

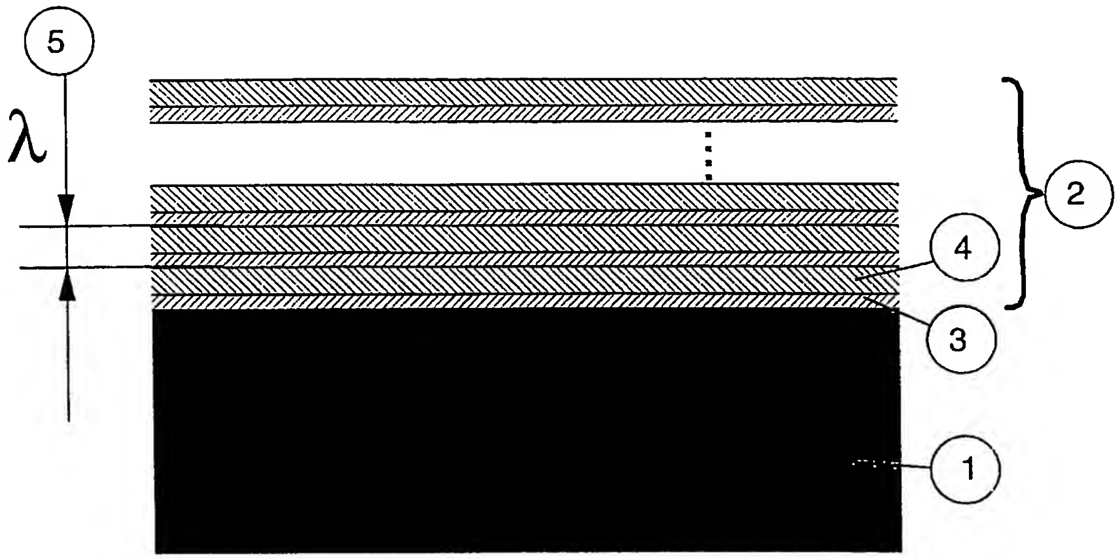

Figure 1

INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00564

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: C23C 14/06, C23C 30/00, B23B 27/14
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: C23C, B23B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

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Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI, JAPIO

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0701982 A1 (SUMITOMO ELECTRIC INDUSTRIES LIMITED), 20 March 1996 (20.03.96), page 2, line 1 - line 12; page 3, line 8 - line 48; page 5, line 1 - line 41, abstract, claims 1-4,8,11,17,18 --	1-8
X	EP 0592986 A1 (SUMITOMO ELECTRIC INDUSTRIES, LIMITED), 20 April 1994 (20.04.94), page 2, line 32 - line 38; page 2, line 50 - page 3, line 53; page 4, line 30 - line 41, page 5, line 39 - line 49; claims 1,4,10; abstract --	1-8
X	EP 0709483 A2 (SUMITOMO ELECTRIC INDUSTRIES, LTD), 1 May 1996 (01.05.96), page 2, line 1 - line 21; page 7, line 10 - line 15, claims 1,5,33, abstract --	1-8

[X] Further documents are listed in the continuation of Box C.　[X] See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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INTERNATIONAL SEARCH REPORT

International application No.
PCT/SE 98/00564

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	GB 2110246 A (VSESOJUZNY NAUCHNO-ISSLEDOVATELSKY INSTRUMENTALNY INSTITUT, (USSR)), 15 June 1983 (15.06.83), page 1, line 40 - line 55; page 2, line 5 - page 3, line 5, abstract	1-8

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INTERNATIONAL SEARCH REPORT
Information on patent family members

30/06/98

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